

Ultraviolet Irradiation on the Surface of Mars: Implications for EVA Activities during Future Human Missions

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17 Biocidal or Inhibitory Factors on the Surface of Mars

- (1) solar UV irradiation
- (2) extreme desiccating conditions (i.e., low water activity; a_w)
- (3) low pressure
- (4) anoxic CO₂-enriched atmosphere
- (5) low temperature
- (6) high salts levels [e.g., MgCl₂, NaCl, FeSO₄, and MgSO₄] in surficial soils
- (7) lack of defined energy source free of UV irradiation
- (8) no sources of available nitrogen and carbon
- (9) no obvious redox couples for microbial metabolism
- (10) galactic cosmic rays
- (11) solar particle events
- (12) UV-glow discharge from blowing dust
- (13) solar UV-induced volatile oxidants [e.g., O₂⁻, O⁻, H₂O₂, O₃]
- (14) globally distributed oxidizing soils
- (15) high concentrations of heavy metals in martian soils
- (16) acidic or alkaline conditions in martian soils
- (17) perchlorates in some soils

(Schuerger et al., 2013, *Astrobiology* 13, 115-131.)

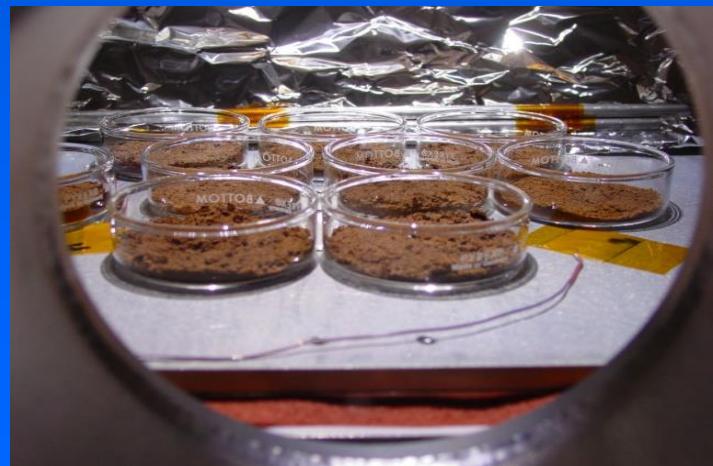
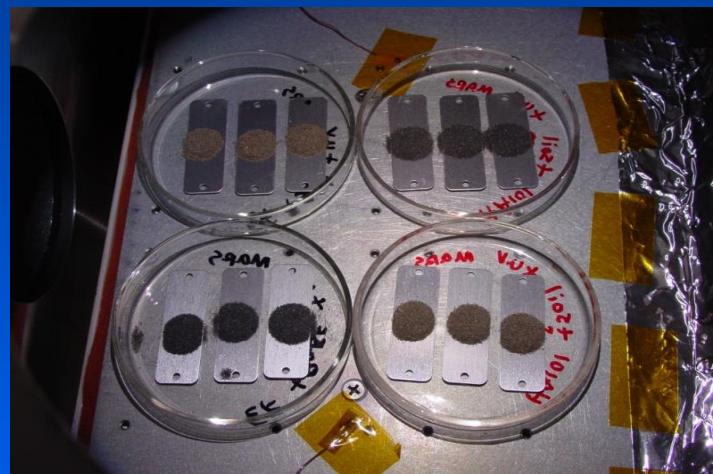
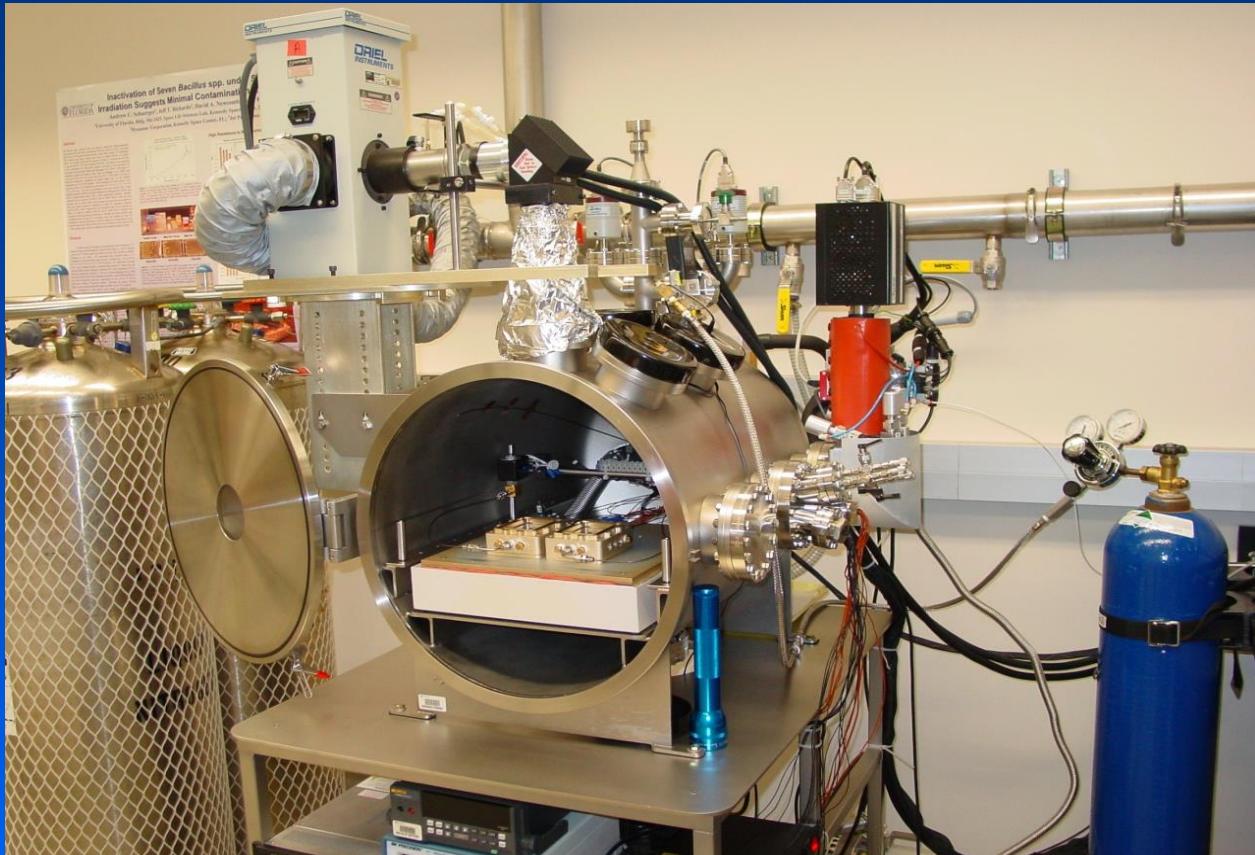
(Stoker et al., 2010, *JGR* 115, E00E2.)

(Beatty et al., 2006, *Astrobiology* 6, 677-732.)

UV Models for Mars

- (1) UV Mars Models:
 - Kuhn and Atreya, 1979, *J. Mol. Evol.*, 14, 57-64.
 - Cockell et al., 2000, *Icarus*, 146, 343-359.
 - Patel et al., 2003, *IJA*, 2, 21-34.
 - Schuerger et al., 2003, *Astrobiology*, 165, 253-276.
 - Moores et al., 2007, *Icarus*, 192, 417-433.
- (2) UVA , UVB, & UVC fluence rates equal to ~38, 8, & 3.5 W/m².
- (3) UV attenuated at 190 nm by CO₂ martian atmosphere.
- (4) +/- 18% at aphelion and perihelion.
- (5) UV Biocidal effects on the surface of Mars are ~1000x greater than Earth.
- (6) Trace of ozone in the martian atmosphere; and generally only in the spring north polar regions (i.e., ozone polar cap).

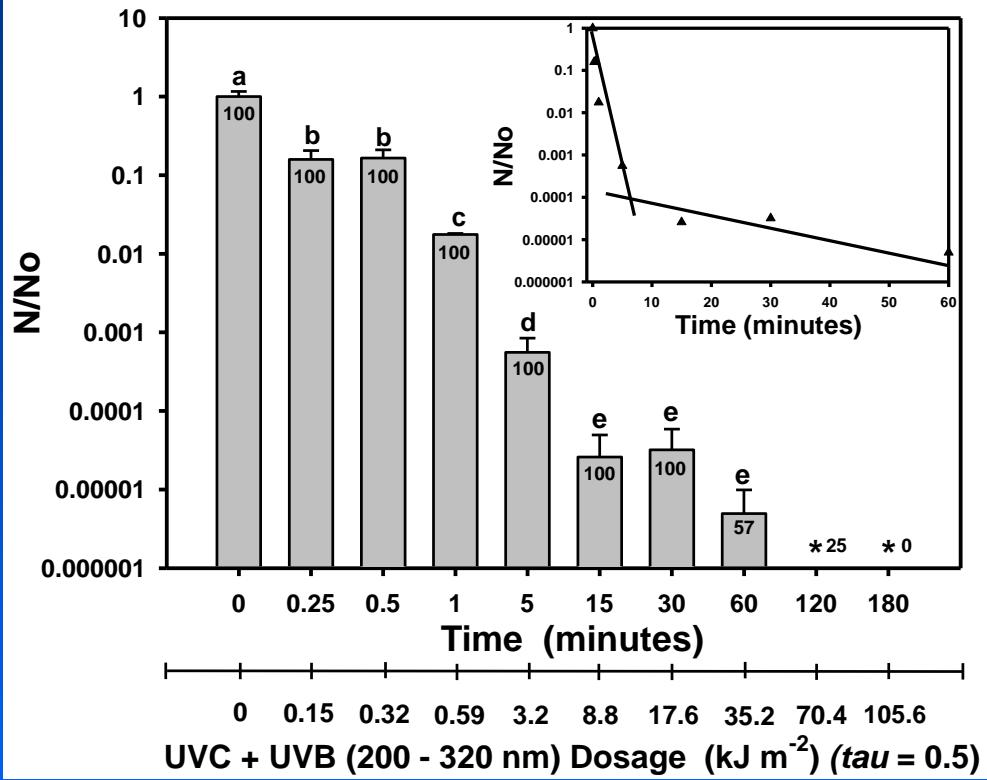
Mars Simulation Chamber (MSC), KSC, FL (described in Schuerger et al., 2008, *Icarus*, 194, 86-100)



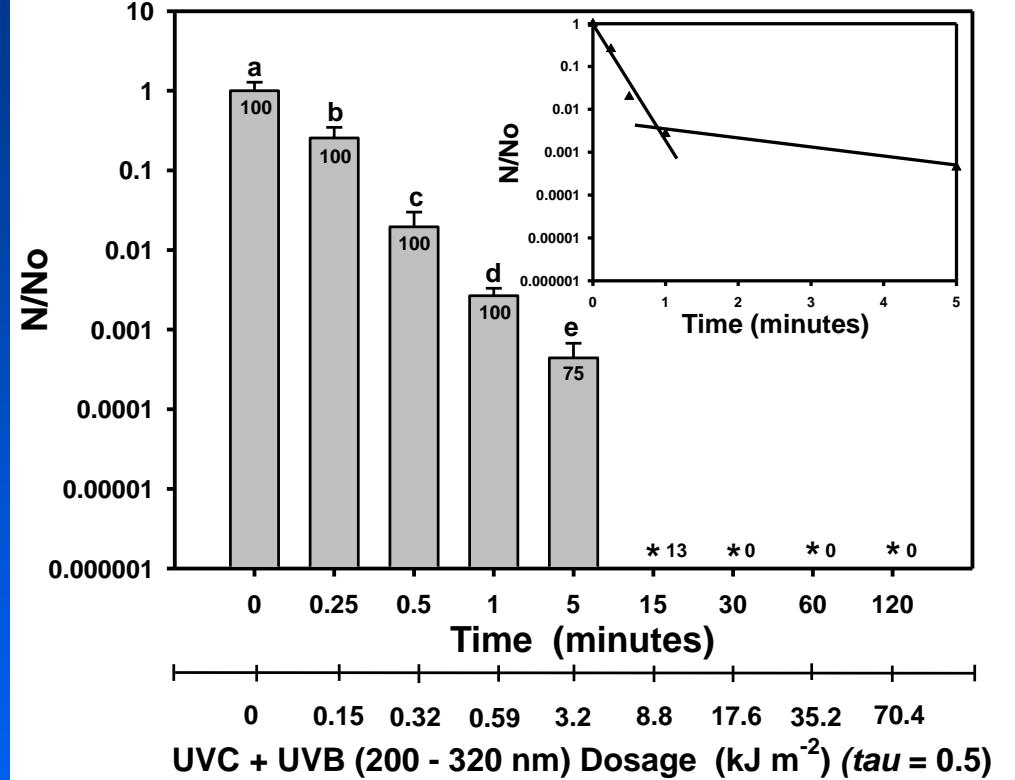
- Pressure: down to 0.1 mbar
- Temp: -100 to +160 °C (programmable)
- Gases: CO₂; O₂/N₂; Mars mix (top 5 gases)
- UV-VIS-NIR: equatorial to polar fluence rates
- Dust loading from τ 0.1 to 3.5

Effects of Mars UV flux on the Survival of *Bacillus* spp.

Bacillus pumilus SAFR-032



Bacillus megaterium KL-197



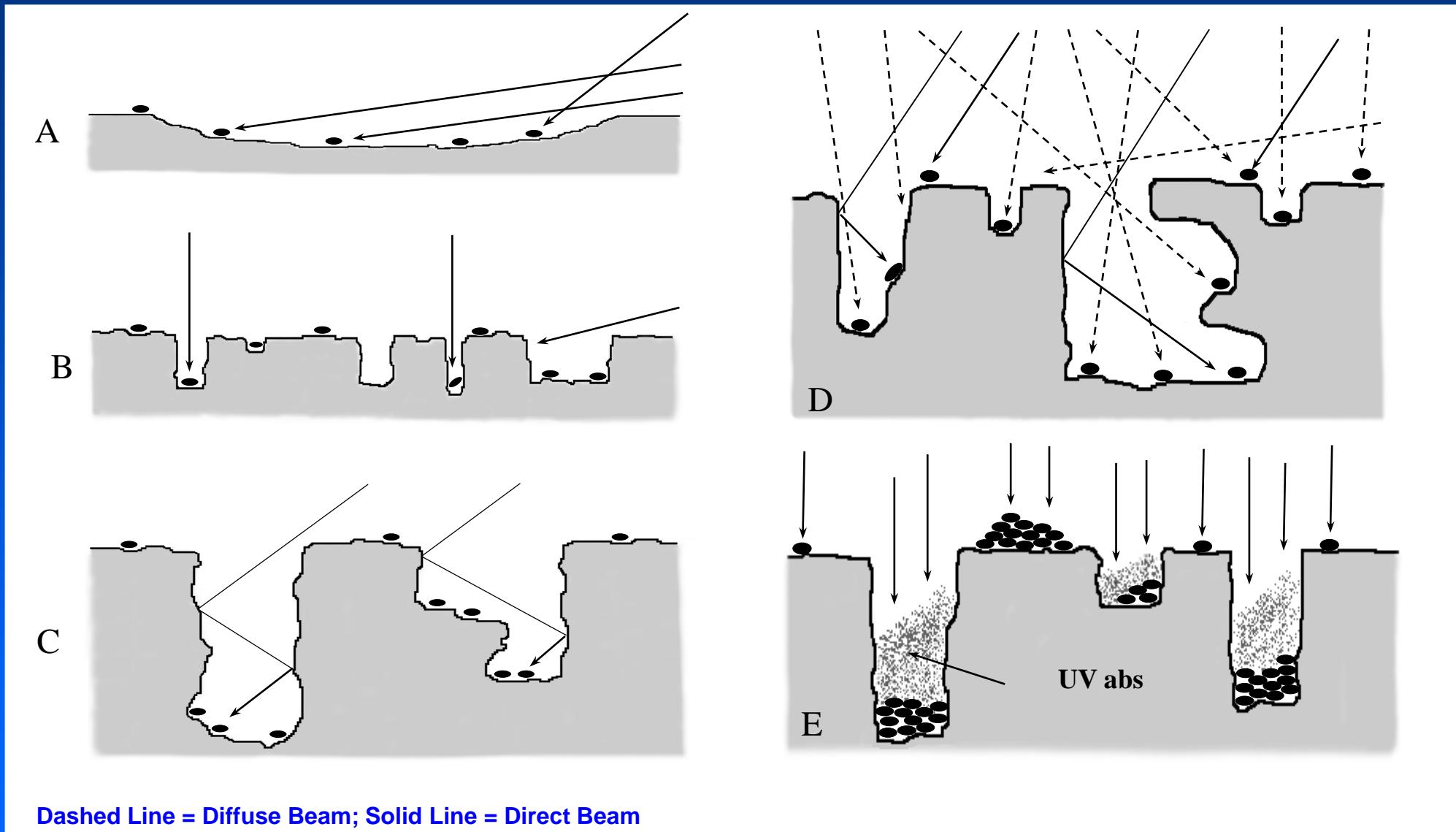
PP Knowledge Gap #1:

- Biocidal UV kill-curves are required for a wider diversity of microorganisms than just *Bacillus* spp. for martian conditions.

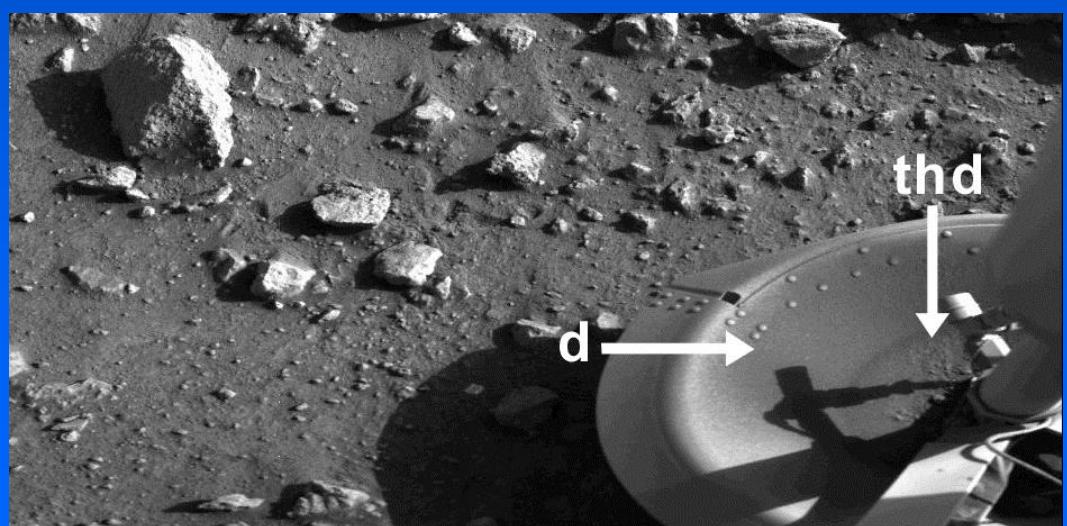
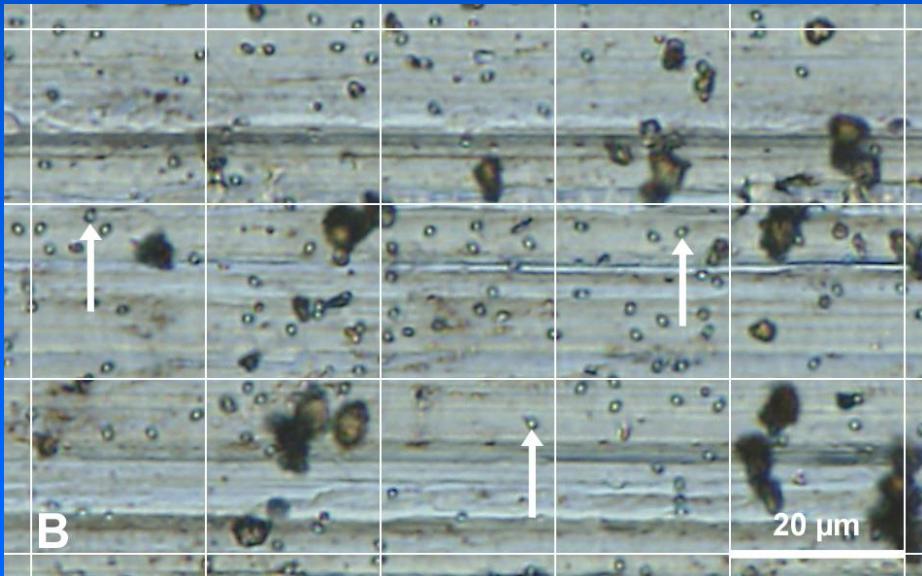
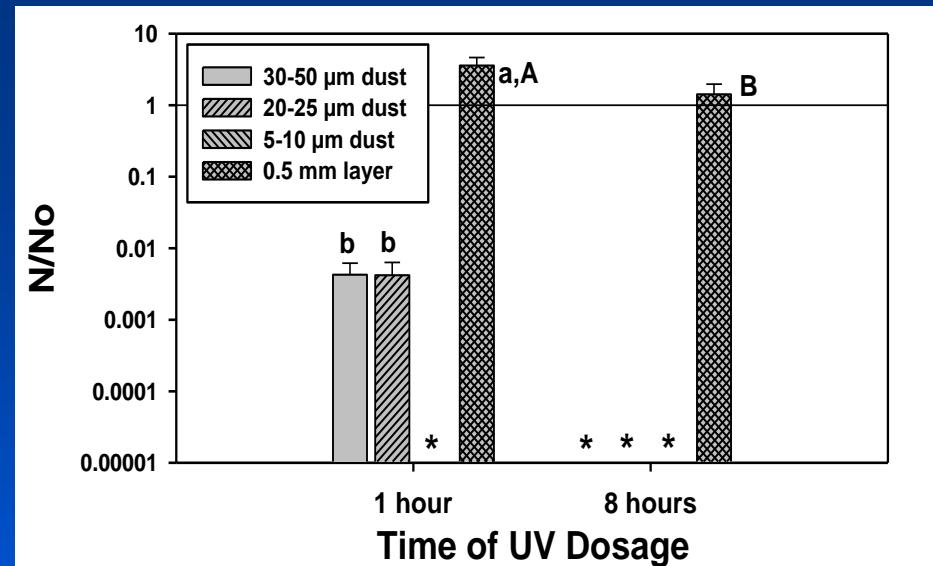
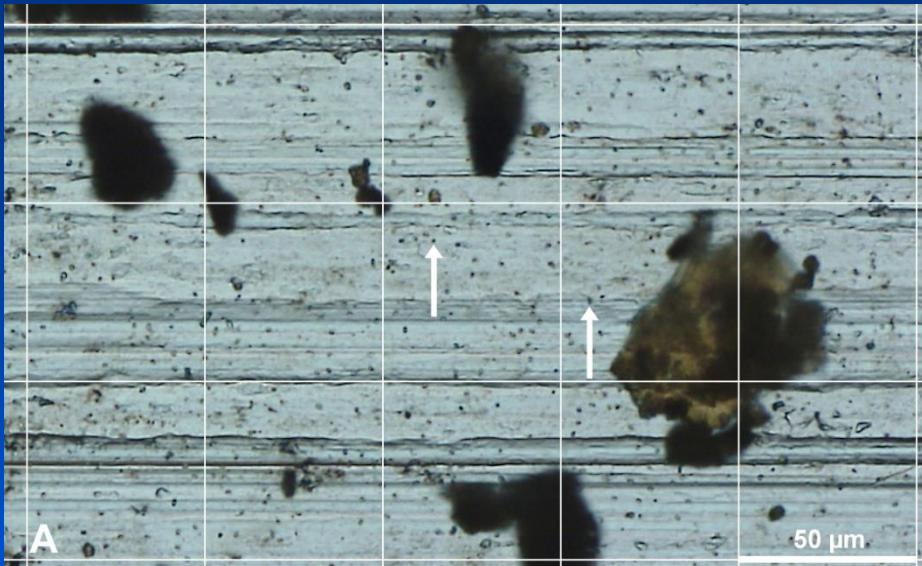
Bacterial species	LD ₉₀ (J m ⁻²)	UV irradiation source	Conditions of spores at time of UV irradiation	Time on Mars LD ₉₀ dose rate at <i>tau</i> = 0.3 (sec)	References
Spore-forming species					
<i>Bacillus</i> spp. (desert soils)	160	Hg-lamp	wet spores	16	Nicholson & Law, 1999
<i>B. anthracis</i>	275	Hg-lamp	wet spores	27	Nicholson & Galeano, 2003
<i>B. megaterium</i> QMB1551	488	Hg-lamp	unknown	48	Setlow, 1988
<i>B. megaterium</i> 25hs1	590	Hg-lamp	wet spores	58	La Duc et al., 2003
<i>B. pumilus</i> 82-2c	620	Hg-lamp	wet spores	61	La Duc et al., 2003
<i>B. pumilus</i> 84-1c	240	Hg-lamp	wet spores	23	La Duc et al., 2003
<i>B. pumilus</i> SAFR-032	2000	Hg-lamp	wet spores	200	Link et al., 2003
<i>B. subtilis</i> HA101	100	xenon-arc lamp	dried spores	10	Schuerger et al. (2003)
<i>B. subtilis</i> HA101	769	deuterium lamp	dried spores	75	Mancinelli & Klovstad, 2000
<i>B. subtilis</i> HA101	70	Hg-lamp	wet spores	7	Munkata, 1981
<i>B. subtilis</i> 168	250	Hg-lamp	wet spores	24	Nicholson & Galeano, 2003
<i>B. subtilis</i> 168	175	Hg-lamp	dried spores	17	Weber & Greenberg, 1985
<i>B. subtilis</i> 168	200	Hg-lamp	wet spores	20	Nicholson et al. 2000
<i>B. subtilis</i> 168	50	Hg-lamp	vegetative cells	4.9	Nicholson et al. 2000
<i>B. subtilis</i> PS832	200	Hg-lamp	dried spores	20	Slieman & Nicholson, 2001
<i>B. sphaericus</i> 9602	190	Hg-lamp	unknown	19	Setlow, 1988
Non-spore forming species					
<i>Acinetobacter radioresistens</i>	<23	Hg-lamp	wet spores	<2.2	La Duc et al., 2003
<i>Deinococcus radiodurans</i>	600	Hg-lamp	exponential cells	59	Moseley, 1983
<i>Escherichia coli</i> AB1157	65	Hg-lamp	wet spores	6.3	Tyrell, 1985
<i>Streptomyces griseus</i>	80	Hg-lamp	dried spores	7.8	Keller & Horneck, 1992

(Schuerger et al., unpublished.)

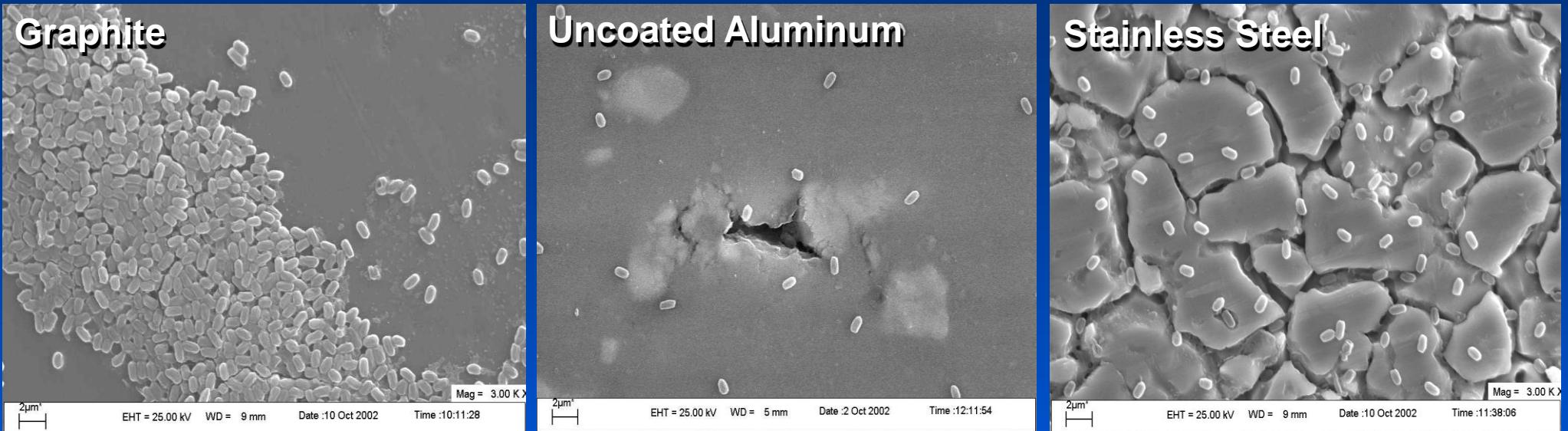
Penetration of UV Irradiation into Spacecraft Materials



UV Scattering around Dust Particles on Spacecraft Surfaces



SEM of *Bacillus subtilis* on Different Spacecraft Components



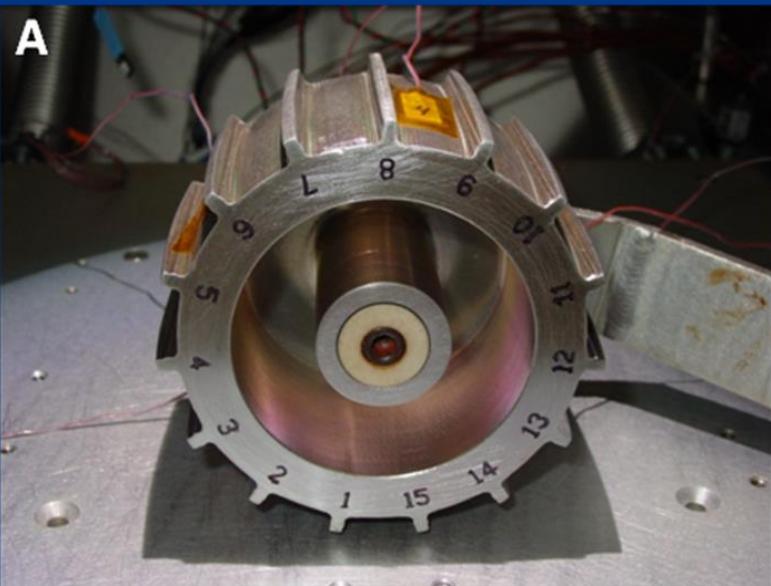
(Schuerger et al., 2005, *Astrobiology*, 5(4), 545-559.)

PP Knowledge Gaps 2 & 3:

- Precisely how do microorganisms adhere to spacecraft materials during pre-launch processing?
- Can spacecraft materials be designed or selected that will prevent the formation of multicellular aggregates on surfaces?

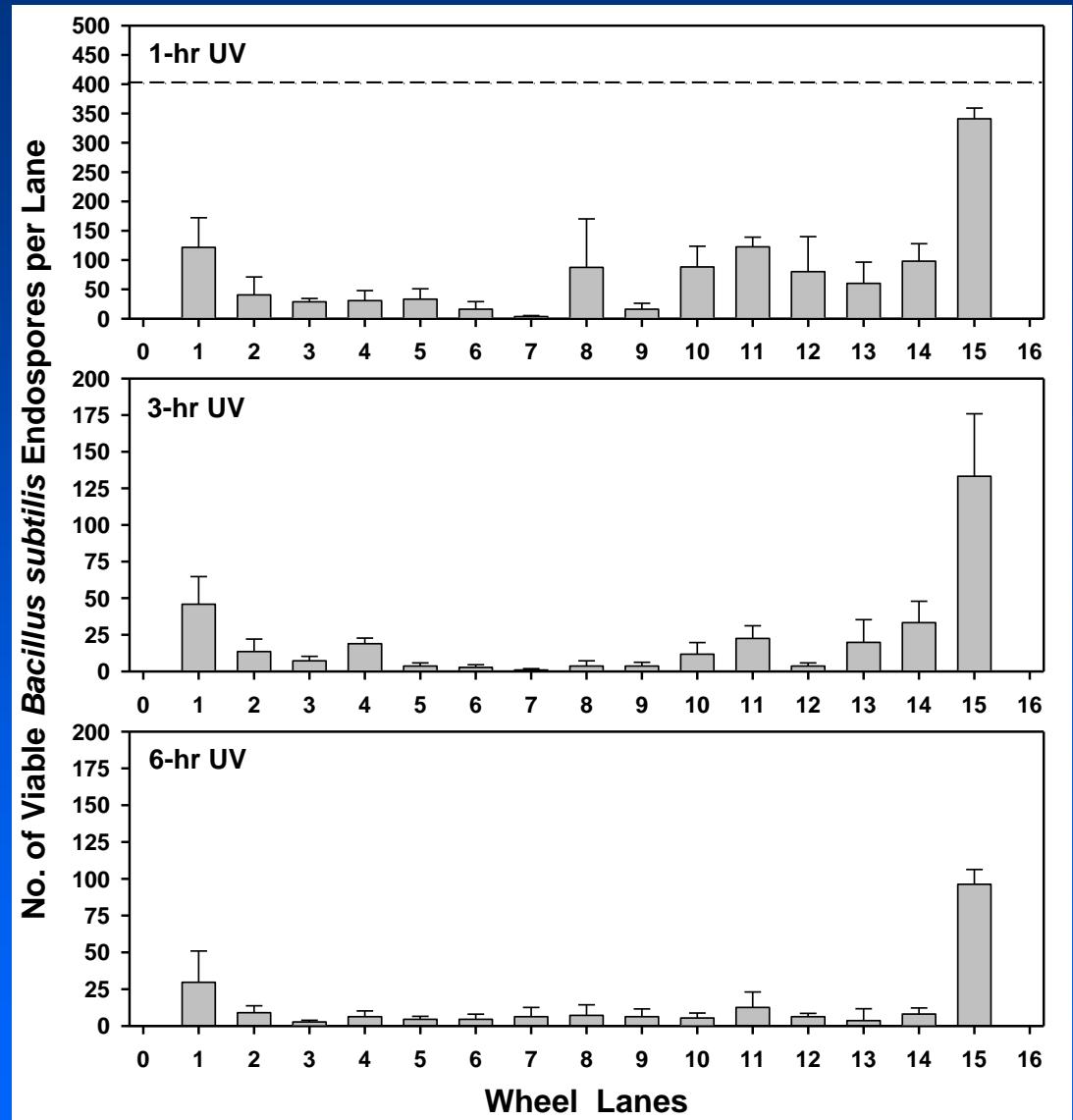
(Schuerger et al., 2005, *Astrobiology* 5, 545-559.)

Penetration of UV Irradiation into Rover Wheel Defects



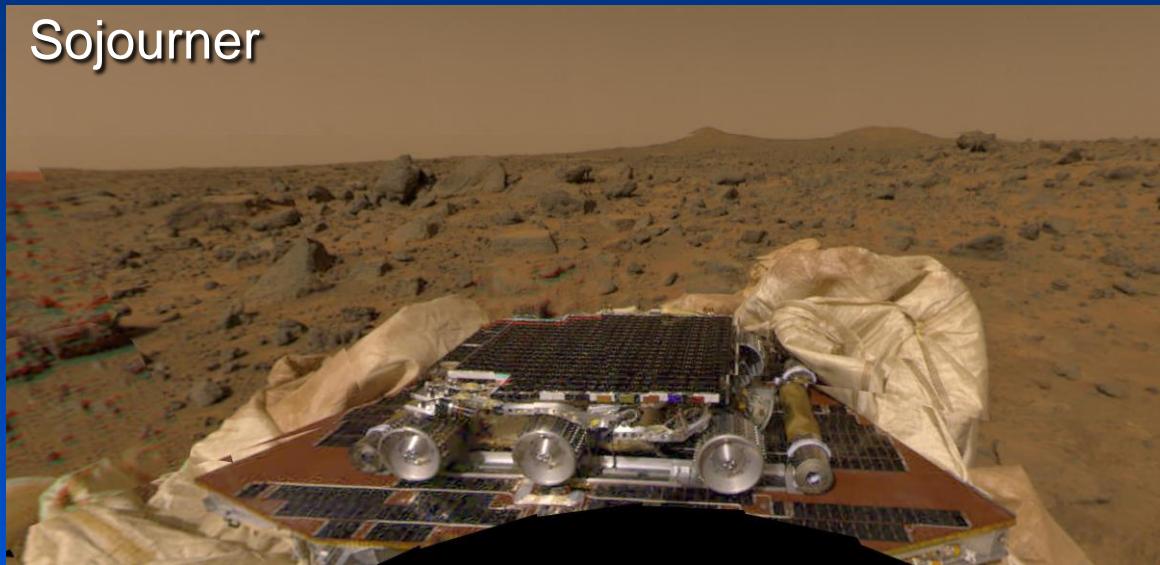
PP Knowledge Gap 4:

- Can rover wheels be designed that do not permit the formation of multicellular aggregates and lack surface defects?



Implications for Air-Bag Landing Systems on Mars

Sojourner



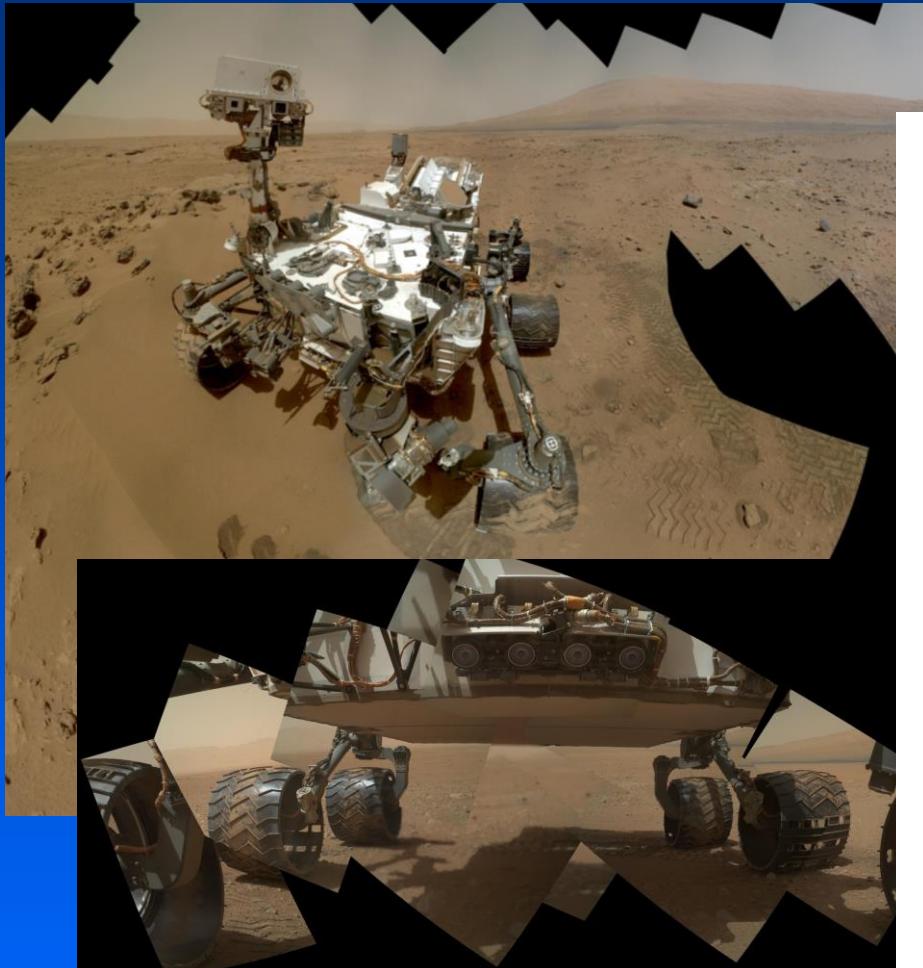
Spirit Lander



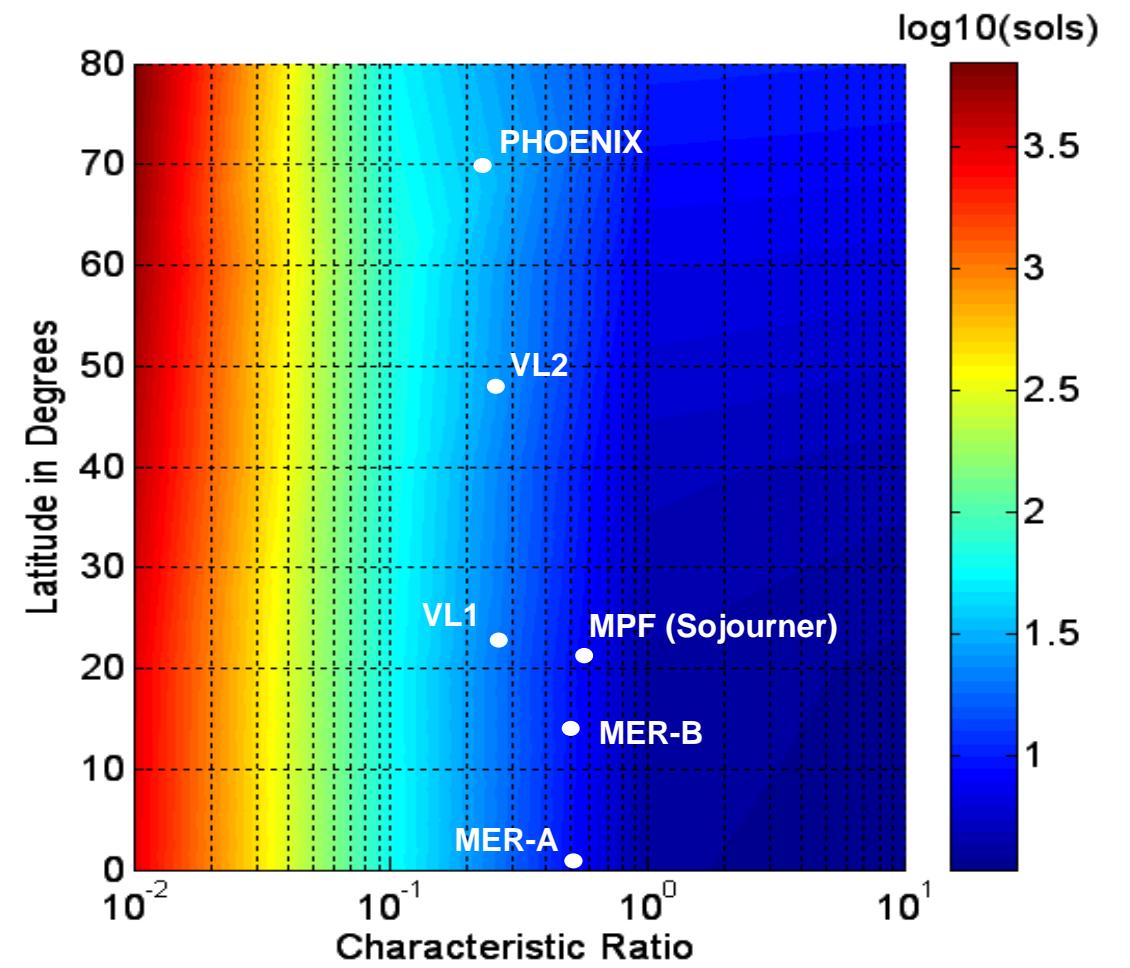
PP Knowledge Gap 5:

- Can rover wheels be “UV-sterilized” (> 6 log reduction) prior to roll-off from landing pads?

Implications for Direct-Descent Landing Systems on Mars



B. pumilus SAFR-032; $LD_{100} = 105.6 \text{ kJ/m}^2$
(based on Schuerger et al. 2006)



PP Knowledge Gap 6:

- Can surface textures on rovers be managed to promote UV biocidal effects on microbial survival?

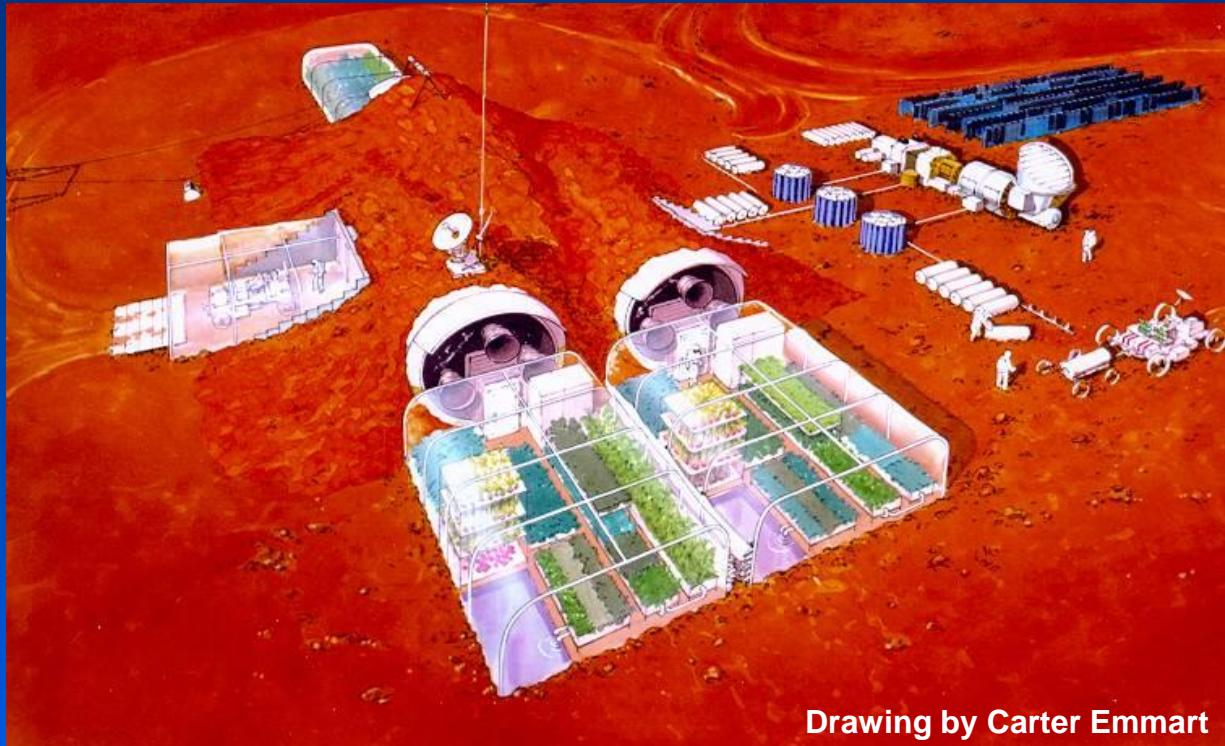
Implications for Human Spacesuit Operations



PP Knowledge Gap 7:

- Can spacesuits be designed to mitigate the adhesion of fine-grained soil particles that might shield attached microbial cells from solar UV?

Implications for Human Exploration of Mars



Drawing by Carter Emmart

Conclusions:

1. Solar UV on Mars is capable of significant biocidal action on terrestrial microorganisms on spacecraft.
2. Although several knowledge gaps exist relevant to biocidal effects of UV on Mars, external surfaces of spacecraft are likely to see >6 orders-of-magnitude reductions in viable bioloads over short periods of time.



Carter Emmart, copyright 1996

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